Sometimes the frontiers or challenges in amateur radio are far removed from the number of new countries that can be worked. Sometimes it's the leap of going beyond what is to what could be.

AMATEUR SPREAD SPECTRUM EXPERIMENTATION

BY HAL L. FEINSTEIN*, WB3KDU

Most of the advances in communications technology have been aimed at producing progressively narrower spectrum occupancy. The traditional wisdom has been that if signal bandwidth is reduced, the spectrum has been conserved. If we look around, we can see that many useful and interesting advances are based on this idea.

To reduce noise and interference, a narrow-band system generally uses a filter that "hugs" the signal. This is taken to the extreme in coherent c.w. systems which have a filter so tight that a special reference is needed to help process the signal.

Spread spectrum modulation takes an approach which is 180 degrees opposed to the narrow-band philosophy. Instead of narrow-bandwidth modulation and narrow-band filters, spread spectrum seeks to make its modulation bandwidth very large. In fact, spread spectrum systems usually are designed to have bandwidths much more than ten times the bandwidth of the modulating information. It is not uncommon to find bandwidths of several megaHertz in such systems.

In a world of narrow-band communications, wideband is equated to interference. This is not necessarily the case in a properly designed spread spectrum system. Spread spectrum signals have a property which we might call "signal rarification." This property arises from the fact that a fixed amount of r.f. energy will be spread rather thinly across a large bandwidth, making the energy in any one spot relatively sparse.

Fig. 1 shows the transformation from a narrow-band signal to a spread spectrum signal. First, we start with a standard narrow-band c.w. carrier which has its energy concentrated about a center frequency. Now, by a process to be described later, the signal bandwidth is increased. What happens? The transmitter is now required to deliver power on more than one frequency. Because it has only a fixed amount of power, the transmitter will distribute its power over the entire bandwidth.

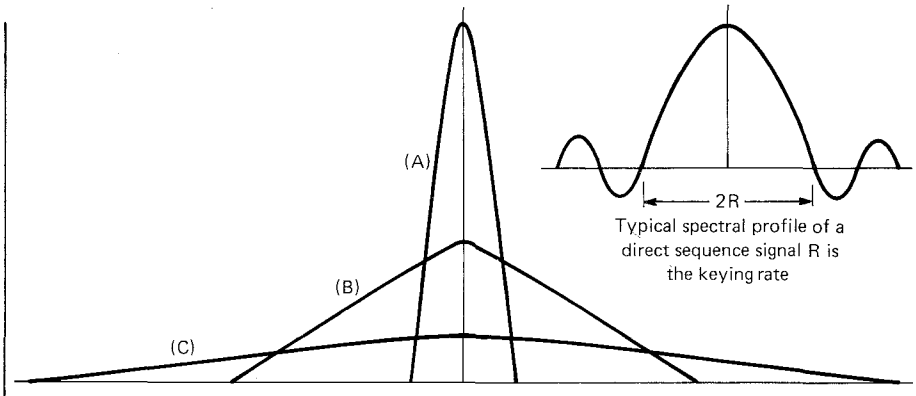

Fig. 1– Width versus power of a direct sequence spread spectrum signal. As the keying rate increases, the bandwidth increases and the peak power falls. (A) A normal carrier with low keying speed, (B) moderate keying speed causes peak power to fall, (C) very high keying speed results in a very wide carrier with small peak power. Notice that the total power remains constant.

As we increase the bandwidth still more, the peak power available to each frequency continues to decrease. At some point, the bandwidth is so wide that someone listening to the signal would say that the signal just went into the noise. In fact, we have spread the signal so thinly that it is below the noise where that listener is. Signals from narrow-band systems should be able to operate in the presence of our spread spectrum signal without any mutual interference.

Of course, we have to have a way of getting our signal back from its spread-out form. This is called "despreading" and will be described later in the discussion of spread spectrum reception. But for now, we have a system which can be made invisible to narrow-band users, using the same band.

Types of Spread Spectrum

There are several ways that a spread spectrum system can dramatically increase its bandwidth. Let's examine the four most popular types.

Direct Sequence mixes a very fast digital keying signal with the desired information.

Frequency Hopping is a standard narrow-band signal the center frequency of which is changed many times a second.

Time Hopping uses pulses with very short key-down times.

Chirp employs a fast swept carrier and is used mostly in radar.

One way to understand spread spectrum is to think of it as a system which transmits two sets of information. First, there is the actual information which we wish to send. Second, there is the process that spreads the signal.

Consider the **direct sequence** form of spread spectrum. This can use frequency-shift keying to cause the spreading. By keying very fast we can get a large increase in bandwidth. So, if we key at one million bits per second, the expected

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bandwidth will be about 2 MHz wide—twice the keying speed.

We need a simple digital circuit to do the fast keying for us. One such circuit is called the **"linear feedback shift register" (LFSR).** The LFSR produces a **pseudo-random noise (PN)** stream which looks much like true random noise on a spectrum analyzer. The fact that a PN source is used is very important to other properties of spread spectrum.

The PN keying source puts a special signature on the signal which is being spread. The signature codes the signal such that a spread spectrum receiver with the same digital circuit can recognize just this spread spectrum signal from a mass of other signals (or noise) with different signatures.

This property creates a special kind of channel which two or more stations can use if all have the same kind of digital code signature. Codes may be set up by several thumb-wheel switches which modify the operation of the code sequence generators in some agreed way.

The ability of a spread spectrum receiver to select only one particular code and reject all others is an important attribute. Of course, it also rejects all narrow-band signals. The key to numerous spread spectrum systems sharing the same frequency space lies in the large number of different types of codes which can be devised. In fact, the number of codes is unknown, and new ones are being discovered all the time. A code needs to have a special property before we can select it for use. This property ensures that the code will not look like any other code for any long stretch of time. The codes must be studied mathematically. Two types have become popular: the so-called **m-length codes** and the **Gold codes.**

Receiving Spread Spectrum

Thus far, we have concentrated on the transmitting side of a direct sequence spread spectrum system. We should take a look at how a receiver is able to process the spread spectrum signal. Fig. 2 shows a greatly simplified block diagram of a direct sequence system. The receiver portion has many processes which should be familiar to most radio amateurs. The difference comes with an interesting new stage which is called the **correlator.**

The correlator performs an operation similar to detection of a signal. Like a product detector, the correlator requires a local reference which is the same as the PN code sequence generator used by the transmitter. The function of the correlator will be to *despread* the signal and recover the modulation information.

The correlator has three ports. One is a local PN code reference. The second is the raw wideband r.f. which is usually beat down to a low center frequency. The last port is the output port and will contain the recovered transmitted information. The correlator works by making comparisons between the local reference and the incoming spread spectrum signal.

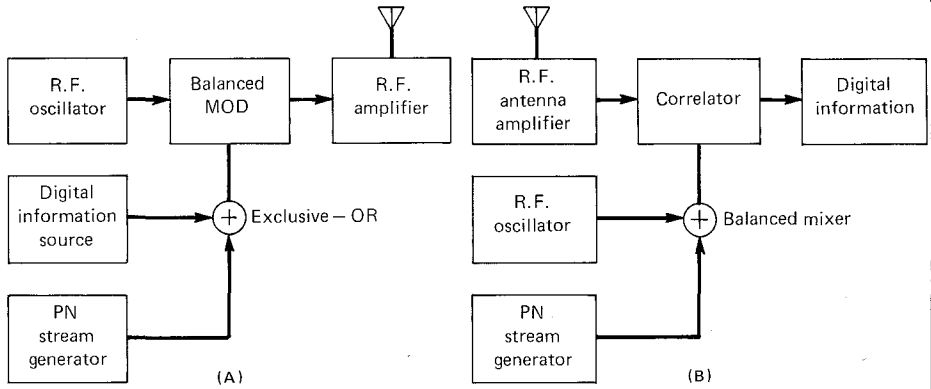

Fig. 2– (A) The functions of a direct sequence transmitter. (B) The functions of a direct sequence receiver.

Interference Rejection

Narrow-band signals and other interference in a properly designed system will be largely uncorrelated with respect to the signature code of the spread spectrum signal. This gives it the ability to reduce the effect of the interference.

Interference which actually gets through the correlator process results from the small amount of "chance" signal which just happens to be at the right frequency at the right time. These types of signals will appear at the output of the correlator as noise. Other spread spectrum signals will be a source of noise as well.

Such noise will grow with the amount of frequency space occupied and the spectral characteristics. What we face in this post-correlator noise is a kind of *packing limit* which says that there is a practical limit to the number of signals that can share. This is especially true if they have characteristics which trick the correlator into thinking that they have the right signature.

At some point, the noise will swamp the information in error just as a weak radio signal is buried in noise. When this happens, communication breaks down in much the same way that band overloading happens with conventional narrow-band services.

All this discussion has centered around the direct sequence system. As can be seen, the direct sequence technique gets its name from the use of the PN sequence directly keying the carrier. As with other types of spread spectrum, there are some serious problems to be overcome in the design of a direct sequence system.

Synchronization

The most important problem is that of synchronization of the transmitter and receiver PN generators. These generators must be in exact step for the system to work. It is a property of the PN streams that a delay of one bit in the correlator will cause the entire signal to be uncorrelated with the local reference. This means that the signal will be rejected as interference.

The ability to properly synchronize the two PN streams is one of the hardest. Quite complex schemes have been devised to deal with this problem. One such technique is called **"dithering."** Using this technique, the PN generator clock is rocked back and forth in speed a very small amount around the known clock speed of the incoming signal. The rocking is not more than half of the clock cycle either way. As the PN speed is rocked slightly forward, the correlator will report a slight decorrelation because the two PN codes are not locked. When the speed of the PN generator is rocked slightly back, the same effect takes place.

Suppose the incoming system speeds up a small amount. Because the receiver is rocking back and forth a small amount, the correlation readings will show an improved correlator output when the local reference speeds up. The output of the correlator is sampled and fed back to a clock-locking circuit which controls the rocking. This feedback will cause the clock frequency to move up or down, depending on where the best correlator output is found.

Because this operation is going on in the thousands or millions of bits per second range, you can see that some precision circuits are needed. Stability is critical to a well-designed system. It is possible to use a slower PN code for direct sequence systems, but there will be a small bandwidth to contend with, less interference rejection capability, and a falloff in other desirable parameters for such a system.

The problem of **handshaking** is also a complex one. This refers to getting the receiver and transmitter PN generators going at the same time. Again, because the systems operate in the microsecond range, this problem is not insignificant. Usually, a solution lies in transmitting a

control signal using a normal narrow-band modulation technique. The control signal will contain precise instructions to the receiver on where and when to begin spread spectrum reception. This kind of signal is called a **preamble**. One system uses the precise instant when the preamble ends to start the system going, although this system was good for only slow rate spread spectrum with the accompanying drawbacks.

The direct sequence system can be jammed by a *noise jammer*. This beast will find the center frequency of the direct sequence spread spectrum signal and generate lots of noise. The noise jammer tries to get as much "chance" noise past the correlator as possible. Rejection of noise and intentional jamming are properties of interest to the military services. There are various ways to get around these problems. The interested reader will find a good description of these techniques in the publications cited in the bibliography at the end of this article.

Near/Far Effect

A rather important phenomenon which is associated with spread spectrum is that of the so-called **"near/far effect."** This arises from the fact that the strength of a spread spectrum signal is above the noise close to the transmitting station and below the noise (this, essentially invisible) starting at some distance from the transmitter. In the near area, a spread spectrum signal plays havoc with narrow-band users in the same area. This is not all bad, because this permits us to use fairly straightforward monitoring and direction-finding techniques to locate an interfering spread spectrum signal.

On-the-Air Experiments

In March 1981 the Amateur Radio Research and Development Corp. (AMRAD), which is a club of over 600 amateur radio experimenters, obtained **S**pecial **T**emporary **A**uthority (STA) from the FCC to begin on-the-air experiments with spread spectrum. There were originally four experiments approved by the FCC, and the STA was amended to include a fifth for three stations. The goal of these experiments was to investigate the usability of spread spectrum in the amateur radio service.

Experiment #1 consisted of frequency hopping experiments in the 80-, 40-, and 20-meter bands using commercial/military frequency hopping gear. These tests were carried out between W4RI, K2SZE, and WA3ZXW in Washington, DC, Rochester, NY, and Annapolis, MD, respectively. These tests allowed many observations to be made in the presence of different conditions in the h.f. bands. Briefly, these tests showed that the frequency hopper worked well in the presence of intermittent c.w. signals, but not as well in the phone portions of the bands when s.s.b. signals are "wall to wall." Another article details the results of this experiment.[1]

Experiment #2 deals with conversion of surplus CB gear for frequency hopping in the 10-meter band. Various groups in Washington, DC, and Texas are interested in this experiment. Construction is underway using CB gear employing type 858 synthesizers with modifications performed on their loop filters to allow faster hopping lock-up.

Experiment #3 is the use of direct sequence spread spectrum in the 420 MHz band. The experiment is geared to use a slow code rate at first, then increase the speed as experience is gained.

Experiment #4 uses direct sequence spread spectrum to improve the multipath performance of **Earth-Moon-Earth (EME)** communications. This experiment is to be carried out by W3PJM using the 84-foot dish at Cheltenham, MD.

Experiment #5 (just added) involves 2-meter tests of a frequency hopping system designed by N5EZV. It uses conventional narrow-band f.m. modulation on a carrier which hops between 16 or more discrete frequencies at rates up to 60 hops per second. These experiments are to be carried out by N4EZV, W4RI, and WB3KDU.

Self Policing

One of the areas of concern is the ability of amateurs to continue to be self policing using this new mode of communications. Spread spectrum is inherently difficult to receive if the receiver is not in possession of the code used by the transmitter. It is also hard to estimate the code by monitoring a spread spectrum signal if the code is complex.

After some discussion, a group of AMRAD members began investigation of ways of receiving spread spectrum without knowing the code used. The goal is to produce a low-cost monitoring system.

Conclusion

The FCC has been a driving force behind amateur radio spread spectrum activity. The FCC is now considering the adoption of rules (Docket 81-414) which will permit spread spectrum emission in the 50, 144, and 220 MHz bands with certain restrictions.

Spread spectrum is a new modulation technique which is only entering the civilian domain. Formerly, it was the province of the military, who took advantage of its signal-hiding, privacy, and anti-jamming properties. But, interest has been growing in the commercial sectors due to spread spectrum's unique spectrum sharing potential. Innovation is required to devise low-cost designs. As the head of a major military electronics company said recently, "We know spread spectrum can be done because we've done it, but can it be done cheaply—that's the real question."

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